

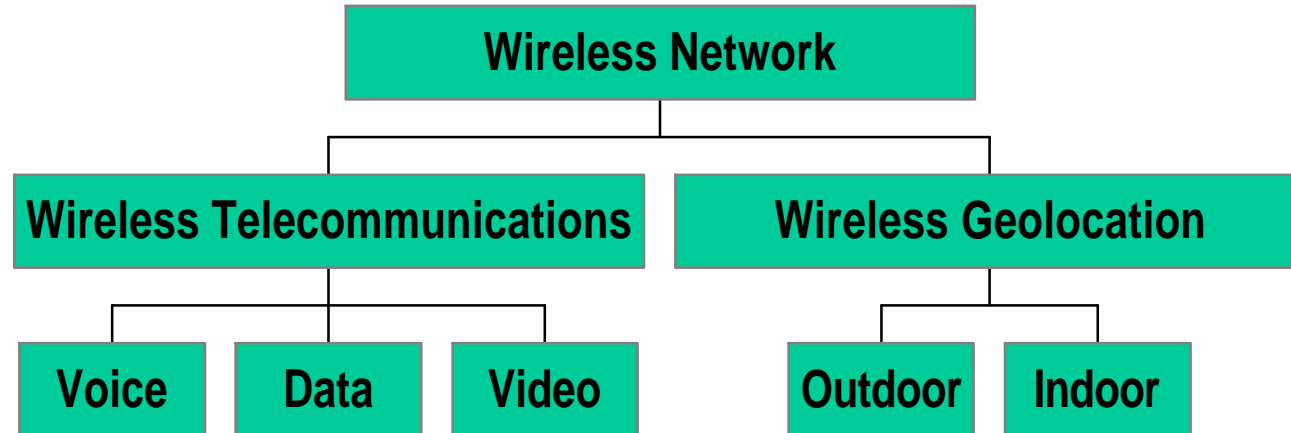


A Framework for Indoor Geolocation using an Intelligent System

Chahé Nerguizian, Charles Despins and Sofiène Affes



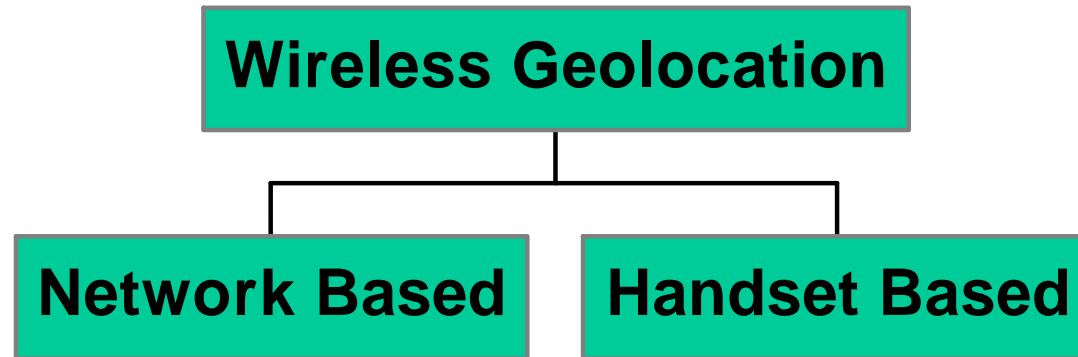
Wireless Applications



- **Telecommunications and Geolocation applications have different objectives**
- **Basic function of a Wireless Geolocation system is to:**
 - Gather a particular information about the position of a Mobile Station (MS)
 - Process that information to form a location estimate
- **The particular information could be:**
 - Received Signal Strength (RSS)
 - Angles Of Arrival (AOA)
 - Times Of Arrival (TOA)
 - Time Differences Of Arrival (TDOA)



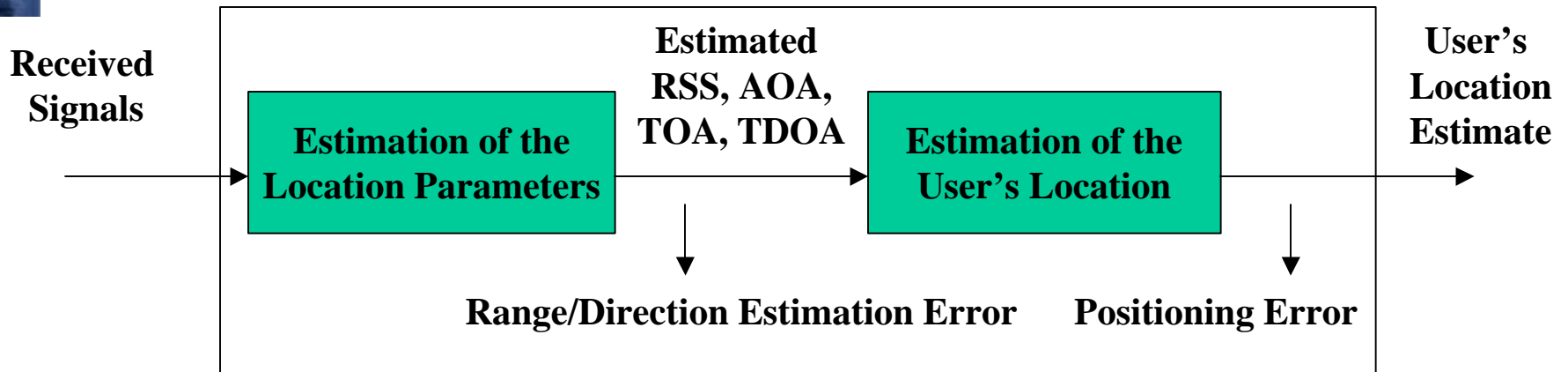
Positioning System Classifications



- **In Handset Based Geolocation, MS receives signals from the Fixed Stations (FS) and computes its own location**
- **In Network Based Geolocation, FSs receive signals from the MS and send the information to a Control Station (CS) where the MS's location is computed**



Geolocation Process



- **Sources of Error:**

- Receiver's equipment
- Noise and Interference
- Propagation Channel

- Multipath
- Non-Line Of Sight (NLOS)

} → **Range/ Direction Estimation Error**
(most important impact on location accuracy)

- Non Linear Algorithm → **Positioning Error**

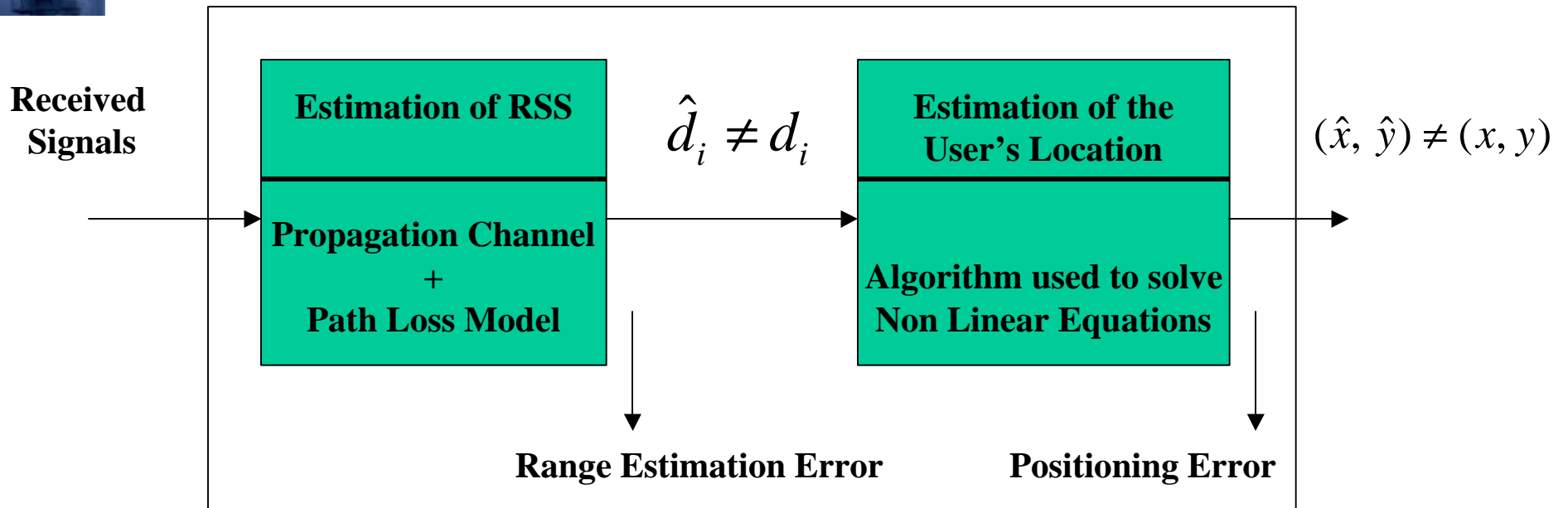


Classical Geolocation Techniques

- **Techniques based on:**
 - **Received Signal Strength (RSS)**
 - **Angle Of Arrival (AOA)**
 - **Time Of Arrival (TOA)**
 - **Time Difference Of Arrival (TDOA)**



RSS Geolocation



- Received signals at 3 FSs and Path Loss Model provide distance or range estimates $(\hat{d}_1, \hat{d}_2, \hat{d}_3)$ between MS and FSs
- Each estimated range gives a circle centered at the receiver (FS) on which the transmitter (MS) must lie



RSS Geolocation (continued)

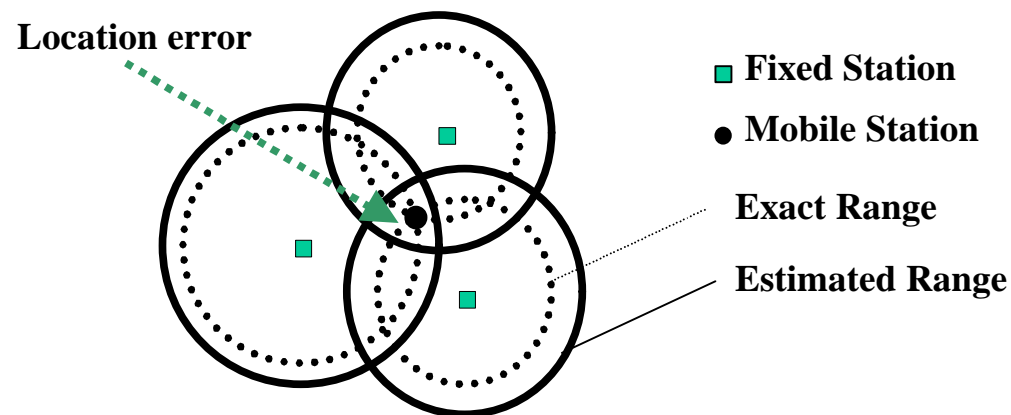
- **Intersection of 3 circles gives :**

- a point, if $\hat{d}_1 = d_1, \hat{d}_2 = d_2, \hat{d}_3 = d_3$

➡ user's location estimate = exact user's location

- a region, if $\hat{d}_1 \neq d_1, \hat{d}_2 \neq d_2, \hat{d}_3 \neq d_3$

➡ user's location estimate with large error





RSS Geolocation (continued)

- **Range Estimation Error due to:**
 - **Multipath**
 - **Non Line Of Sight (NLOS)**
 - **Local Shadowing**
- **Position Estimation Error due to:**
 - **Algorithm used to solve Non Linear Equations**

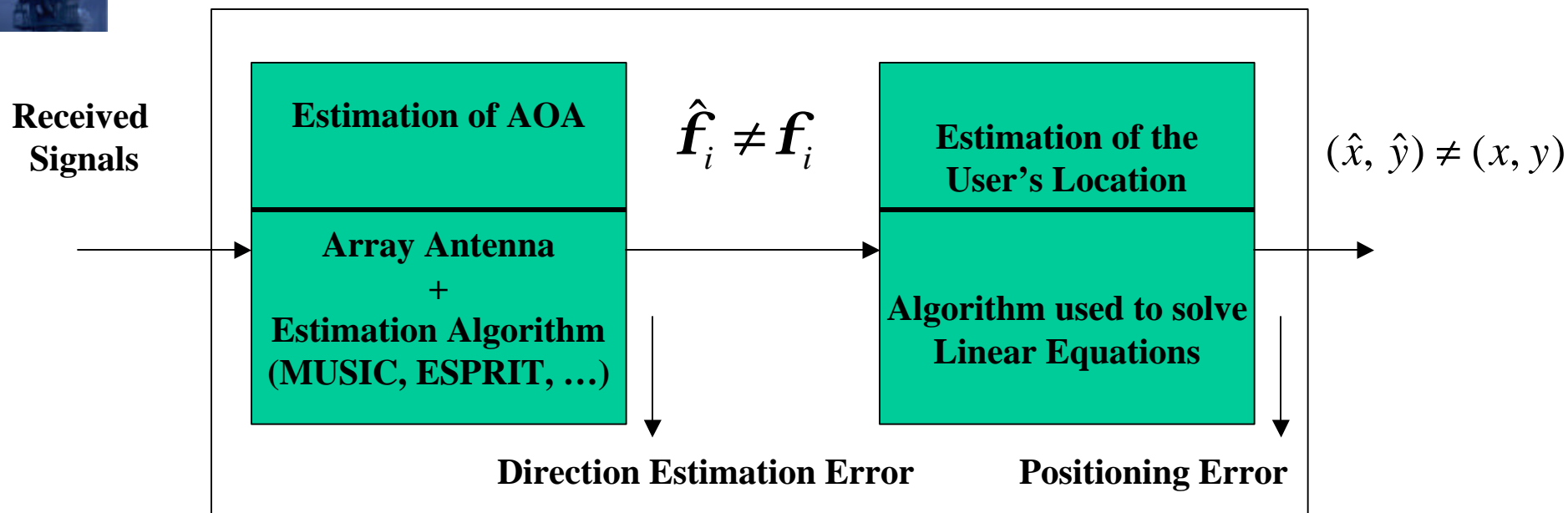
Conclusion

Accuracy of RSS technique depends on:

- **Indoor environment (Multipath, NLOS, Local Shadowing)**
- **Path Loss Model used**
- **Number of FSs used**
- **Algorithm used to estimate user's location**



AOA Geolocation



- Received signals at 2 FSs (array antennas) and estimation algorithm provide angle or direction estimates (\hat{f}_1, \hat{f}_2) between MS and FSs
- Each estimated angle gives a straight line joining the receiver (FS) to the transmitter (MS)

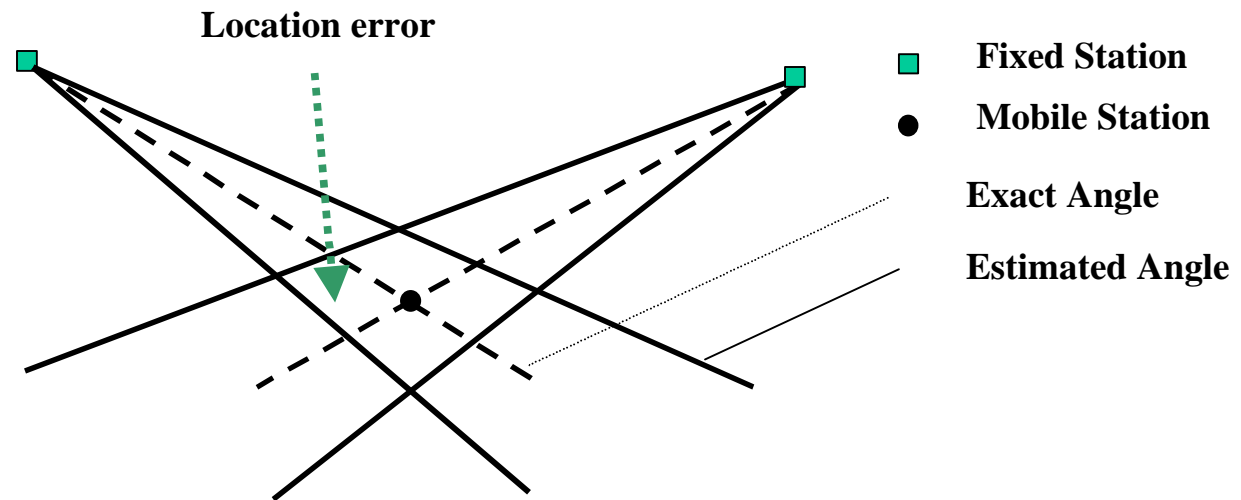


AOA Geolocation (continued)

- **Angular resolution or accuracy of direction measurements (array antennas) induces spread of estimated angle**
- **Intersection of 2 straight lines gives:**
 - a point, if $\hat{f}_1 = f_1, \hat{f}_2 = f_2$
➡ **user's location estimate = exact user's location**
 - a point, if $\hat{f}_1 \neq f_1, \hat{f}_2 \neq f_2$
➡ **user's location estimate with error**
 - a region, if $\hat{f}_1 \neq f_1, \hat{f}_2 \neq f_2$ and angular spread
➡ **user's location estimate with large error**



AOA Geolocation (continued)



- **Direction Estimation Error due to**
 - **Multipath**
 - **Non Line Of Sight (NLOS)**
 - **Angular accuracy of array antenna**



AOA Geolocation (continued)

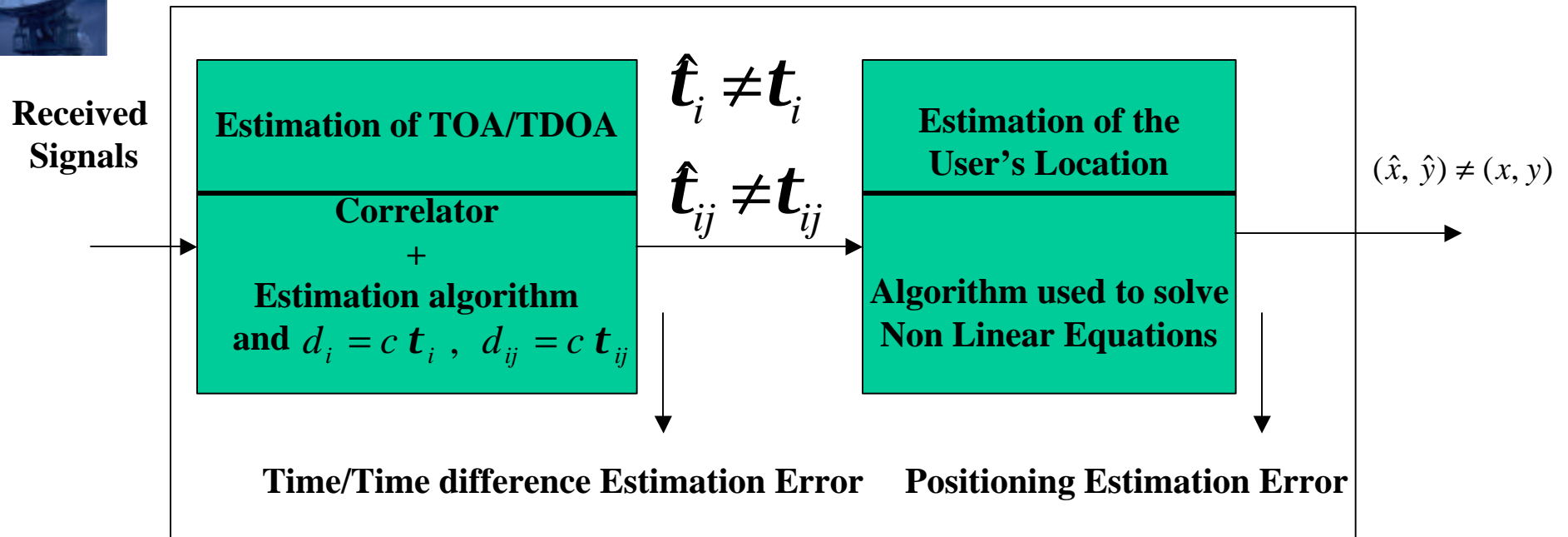
Conclusion

Accuracy of AOA technique depends on:

- **Indoor environment (Multipath, NLOS)**
- **Plane wave/near field propagation model used**
- **Algorithm used to estimate direction of arrival**
- **Angular accuracy of array antenna**
- **Number of FSs used**
- **Geographical location of MS relative to FSs**



TOA/TDOA Geolocation



- Received signals at 3 FSs and estimation algorithm provide time / time difference estimates ($\hat{t}_1, \hat{t}_2, \hat{t}_3 / \hat{t}_{12}, \hat{t}_{13}, \hat{t}_{23}$) between MS and FSs / pairs of FSs.



TOA/TDOA Geolocation (continued)

- **Signal speed of propagation known, time / time difference estimates provides range / range difference estimates**
($\hat{d}_1, \hat{d}_2, \hat{d}_3 / \hat{d}_{12}, \hat{d}_{13}, \hat{d}_{23}$)
- **Each estimated distance (associated to time estimate) gives a circle centered at receiver (FS) on which transmitter (MS) must lie**
- **Each estimated range difference (associated to time difference estimate) gives a hyperbola with foci at receivers (FSs) on which transmitter (MS) must lie.**



TOA/TDOA Geolocation (continued)

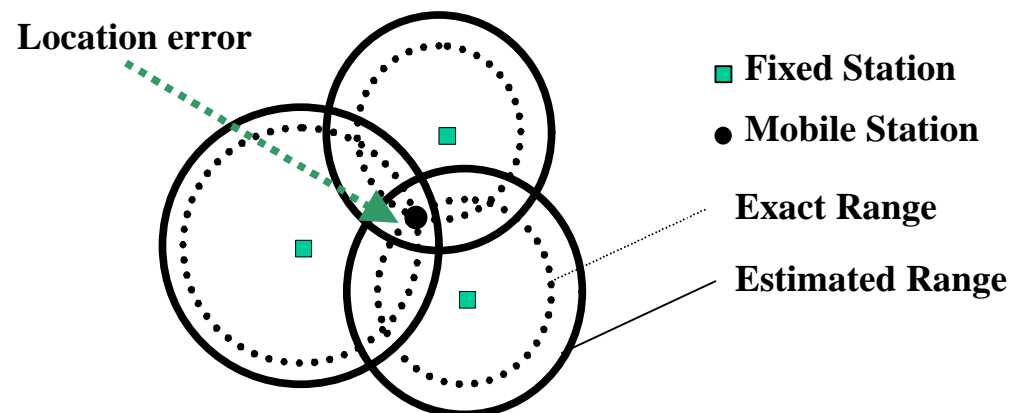
- **Intersection of 3 circles (TOA) gives :**

- a point, if $\hat{d}_1 = d_1, \hat{d}_2 = d_2, \hat{d}_3 = d_3$

- ➔ user's location estimate = exact user's location

- a region, if $\hat{d}_1 \neq d_1, \hat{d}_2 \neq d_2, \hat{d}_3 \neq d_3$

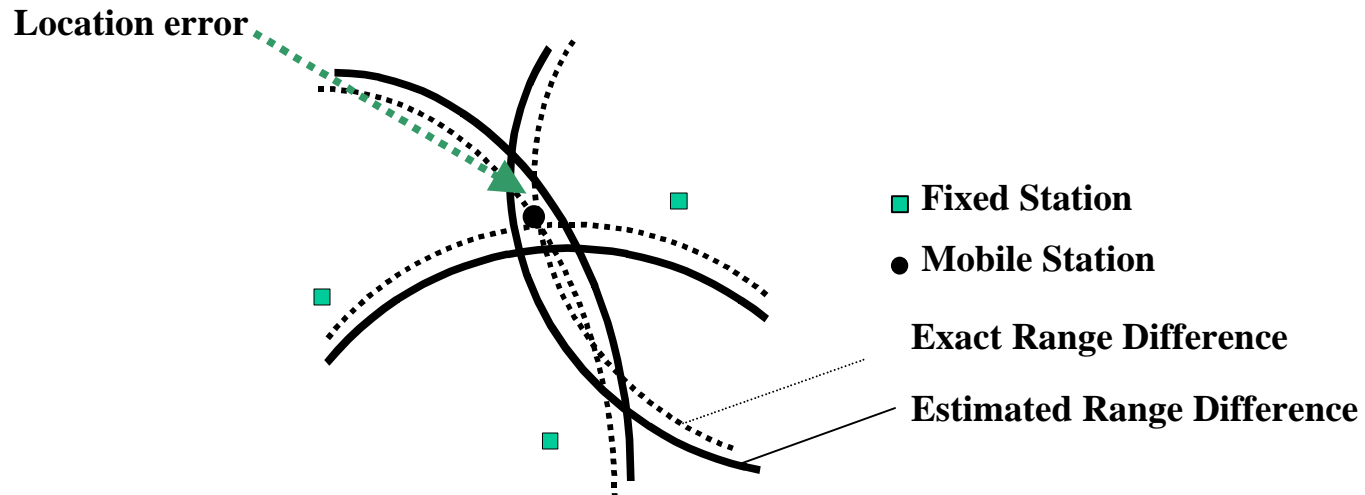
- ➔ user's location estimate with large error





TOA/TDOA Geolocation (continued)

- **Intersection of 3 hyperbolas (TDOA) gives:**
 - a point, if ($\hat{d}_1 = d_1, \hat{d}_2 = d_2, \hat{d}_3 = d_3$)
➡ user's location estimate = exact location
 - a region, if ($\hat{d}_1 \neq d_1, \hat{d}_2 \neq d_2, \hat{d}_3 \neq d_3$)
➡ user's estimate with large error





TOA/TDOA Geolocation (continued)

- **Range / Range Difference Estimation Error due to:**
 - **Multipath**
 - **Non Line Of Sight (NLOS)**
- **Position Estimation Error due to:**
 - **Algorithm used to solve Non Linear Equations**
- **TOA requires a strict time synchronization between transmitter and receivers**
- **TDOA requires only a time synchronization between receivers**

Conclusion

Accuracy of TOA/TDOA technique depends on:

- **Indoor environment (Multipath, NLOS)**
- **Algorithm used to estimate time / time difference of arrival**
- **Number of FSs used**
- **Algorithm used to estimate user's location**
- **Geographical location of MS relative to FSs**



Geolocation Techniques for Indoor Environment

- **Classical Techniques based on:**
 - Received Signal Strength (RSS)
 - Angle Of Arrival (AOA)
 - Time Of Arrival (TOA)
 - Time Difference Of Arrival (TDOA) → most popular one
- **Main source of location error : Multipath in the absence of LOS**

Solution

- Mitigate effect of Multipath
- Use Multipath as constructive information (selected solution)

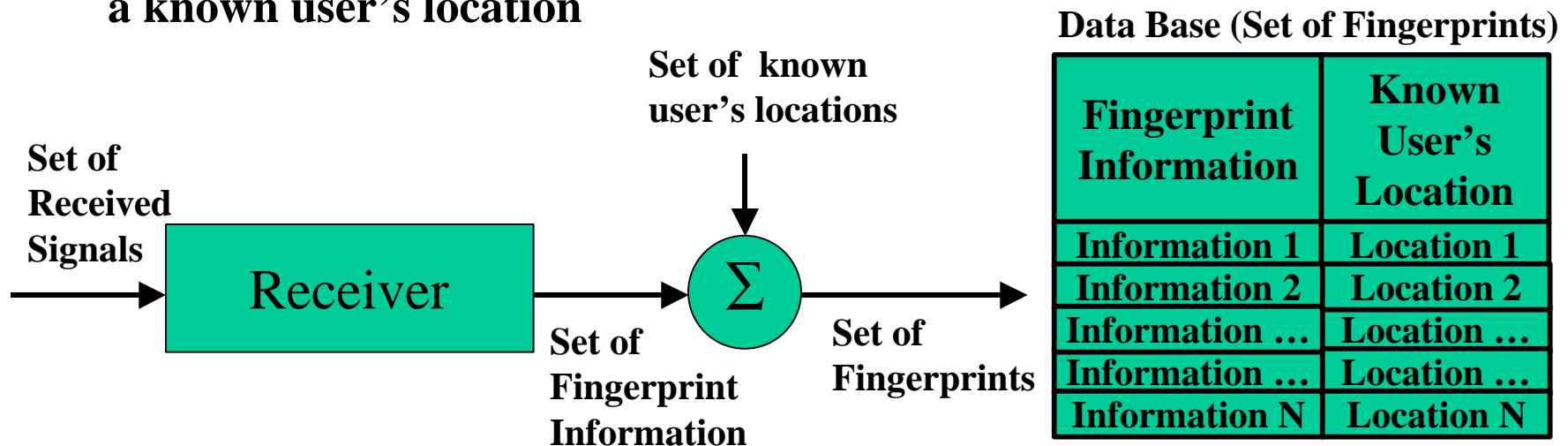
Conclusion

→ **Geolocation Technique based on Received Signals Fingerprint**



Geolocation Technique based on Received Signals Fingerprint

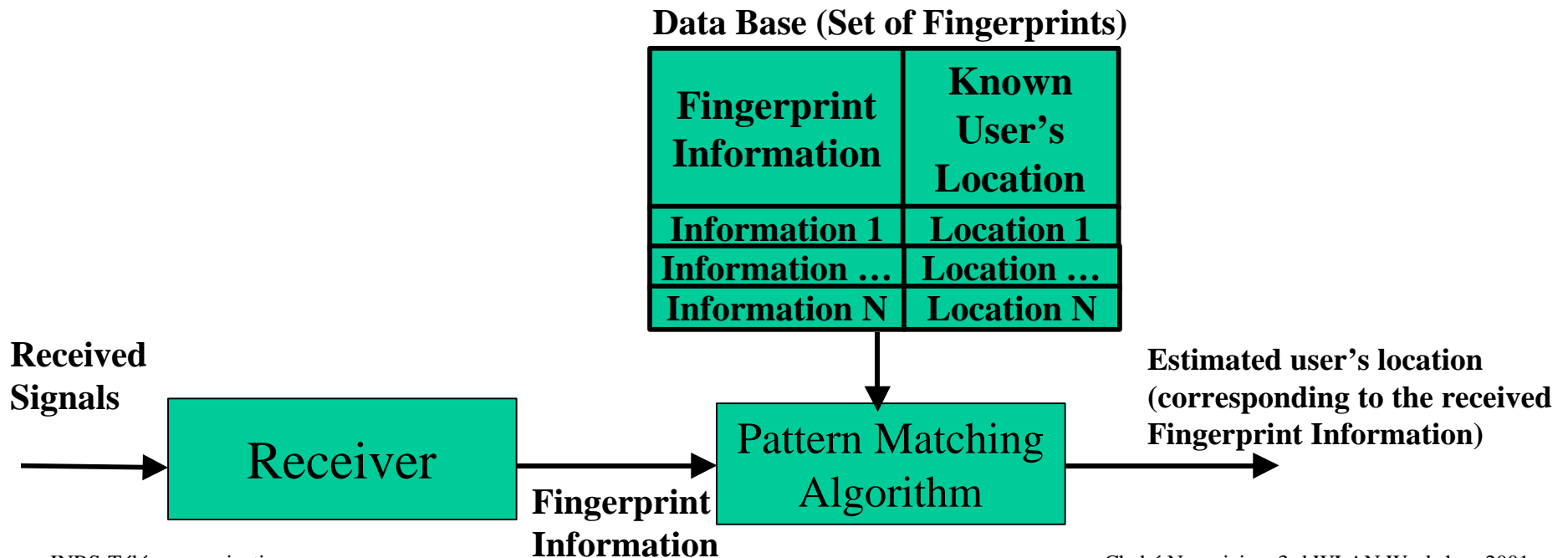
- Operation of Geolocation Technique is based on 2 phases :
 - Off-Line phase (Phase of data collection) or Learning phase
 - Real-Time phase (Phase of user's position location)
- Off-Line phase consists of recording a set of Information (in a database) as a function of the user's location covering the entire zone of interest, forming a set of Fingerprints
- Each Fingerprint corresponds to a Fingerprint information associated to a known user's location





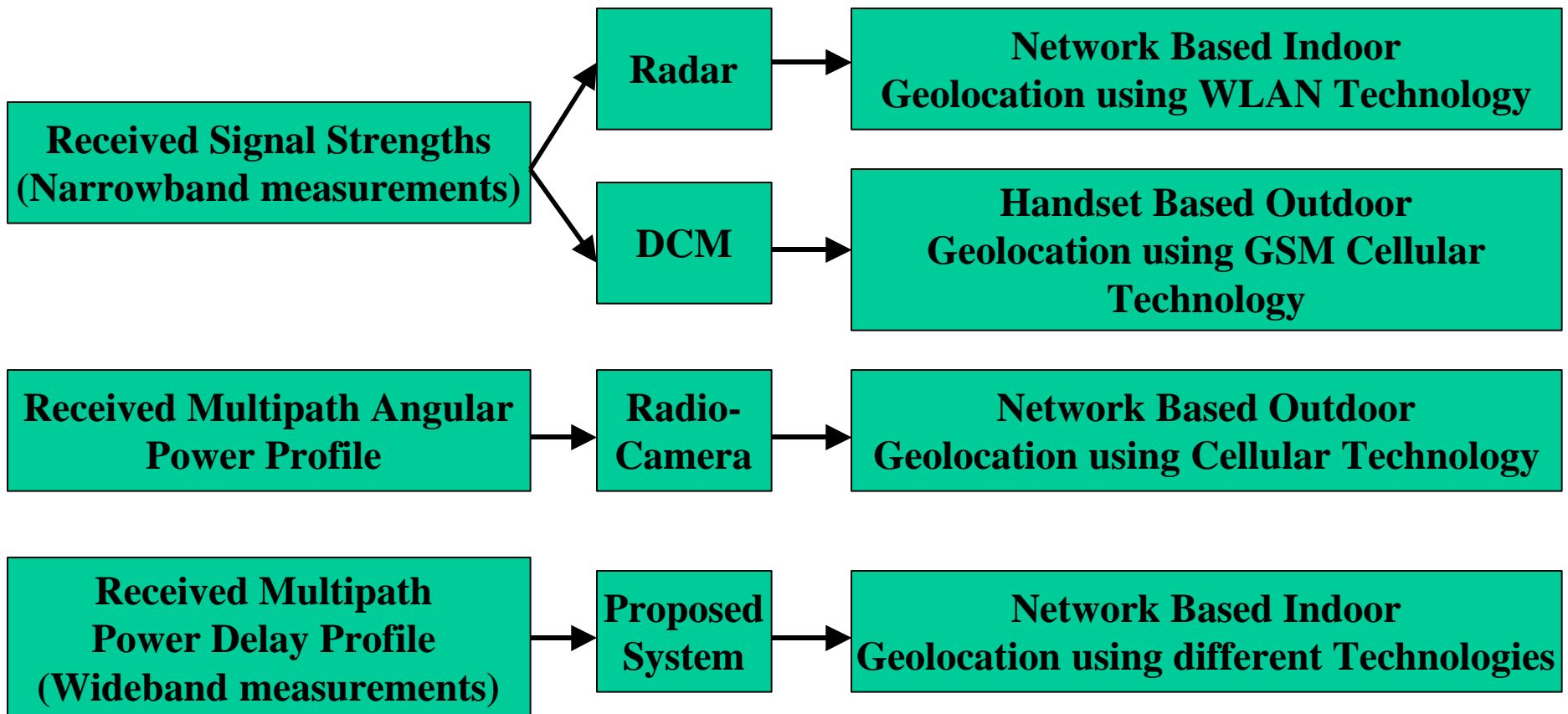
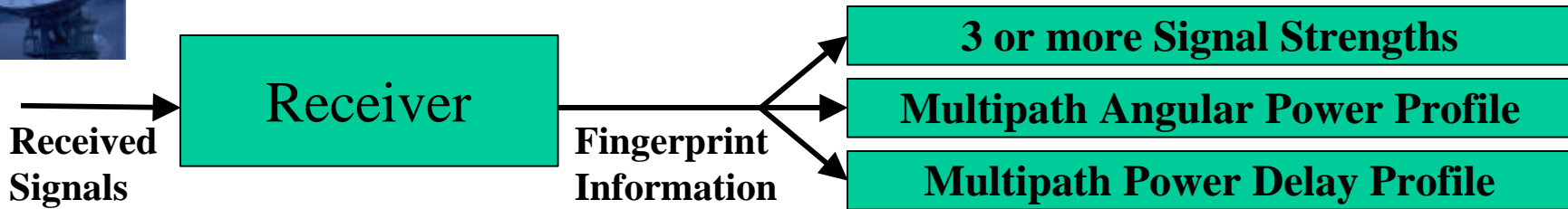
Geolocation Technique based on Received Signals Fingerprint (continued)

- For Real-Time phase, specific Fingerprint Information is obtained from measured received signals and compared with recorded set of Fingerprints (database)
- A Pattern Matching Algorithm is then used to identify the closest recorded information of the database to the measured one, thus defining the corresponding user's location





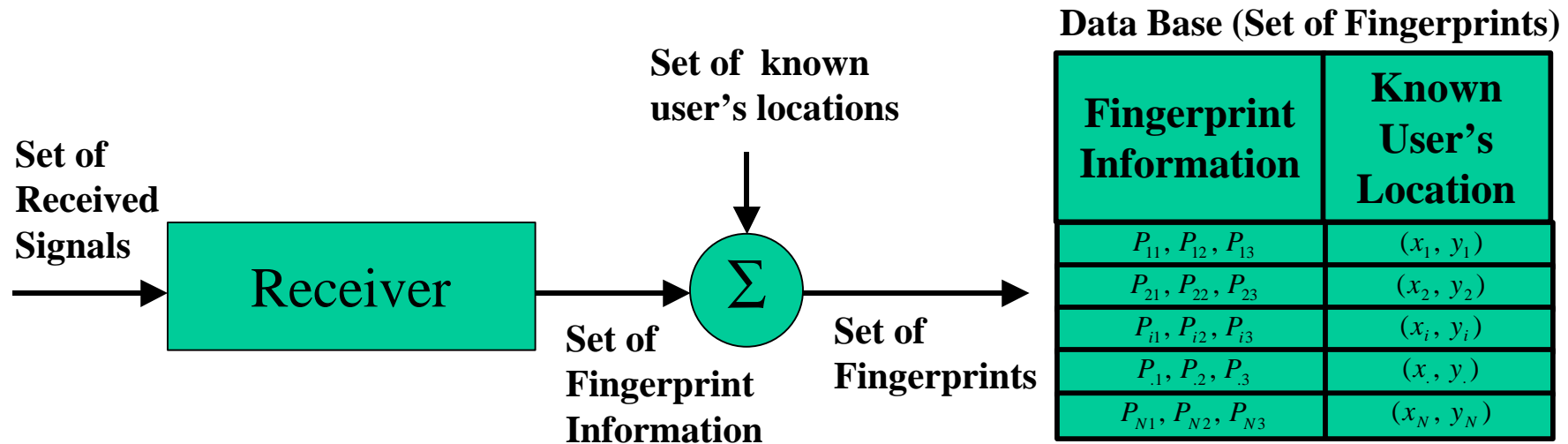
Types of Fingerprint Information





Radar System (Microsoft Corporation)

- RF based system for locating and tracking users inside buildings
- Network based indoor Geolocation
- Operation with WLAN technology
- Fingerprint Information based on Received Signal Strengths (RSS) at 3 Access Points (AP)
- Off-Line phase gives a set of Fingerprints corresponding to 3 Received Signal Strengths (P_{i1}, P_{i2}, P_{i3}) as a function of user's location (x_i, y_i), $\{ i = 1, 2, \dots, N \}$





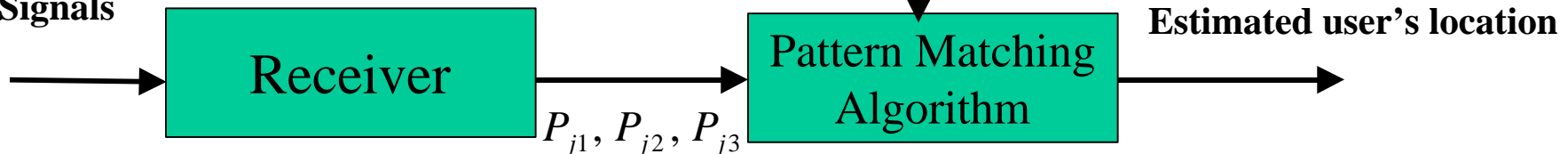
Radar System (Microsoft Corporation) (continued)

- For Real-Time phase, specific (P_{j1}, P_{j2}, P_{j3}) is obtained from measured received signals and compared with recorded set of Fingerprints (database)
- A Pattern Matching Algorithm, using an Euclidean distance (in signal space), chooses location that minimizes distance between specific observed RSSs and recorded set of Fingerprints, and therefore estimates user's location

Data Base (Set of Fingerprints)

Fingerprint Information	Known User's Location
P_{11}, P_{12}, P_{13}	(x_1, y_1)
$P_{.1}, P_{.2}, P_{.3}$	(x, y)
P_{N1}, P_{N2}, P_{N3}	(x_N, y_N)

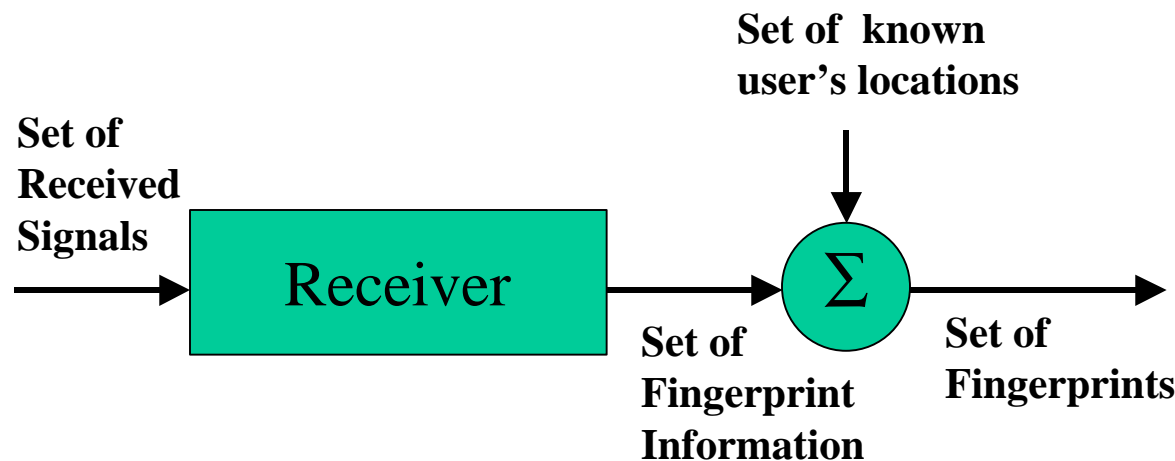
Received Signals





DCM Method (VTT Information Technology)

- RF based system for locating and tracking outdoor users
- Handset based outdoor Geolocation
- Operation with GSM Cellular technology
- Fingerprint Information based on Received Signal Strengths (RSS) at 7 Base Stations (serving cell + 6 strongest neighbors)
- Off-Line phase gives a set of Fingerprints corresponding to 7 Received Signal Strengths ($P_{i1}, P_{i2}, P_{i3}, P_{i4}, P_{i5}, P_{i6}, P_{i7}$) as a function of user's location $(x_i, y_i), \{i = 1, 2, \dots, N\}$



Data Base (Set of Fingerprints)

Fingerprint Information	Known User's Location
$P_{11}, P_{12}, \dots, P_{17}$	(x_1, y_1)
$P_{21}, P_{22}, \dots, P_{27}$	(x_2, y_2)
$P_{i1}, P_{i2}, \dots, P_{i7}$	(x_i, y_i)
$P_{.1}, P_{.2}, \dots, P_{.7}$	(x, y)
$P_{N1}, P_{N2}, \dots, P_{N7}$	(x_N, y_N)



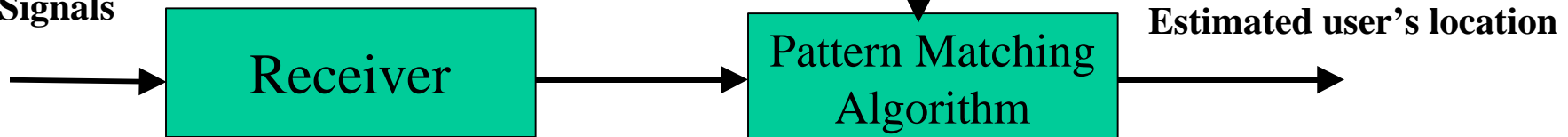
DCM Method (VTT Information Technology) (continued)

- For Real-Time phase, specific $(P_{j1}, P_{j2}, \dots, P_{j7})$ is obtained from measured received signals and compared with recorded set of Fingerprints (database)
- A simple correlation or more advanced Pattern Matching Algorithm is used between specific observed RSSs and recorded set of Fingerprints, and therefore estimates user's location

Data Base (Set of Fingerprints)

Fingerprint Information	Known User's Location
$P_{11}, P_{12}, \dots, P_{17}$	(x_1, y_1)
$P_{1}, P_{2}, \dots, P_{7}$	(x, y)
$P_{N1}, P_{N2}, \dots, P_{N7}$	(x_N, y_N)

Received Signals



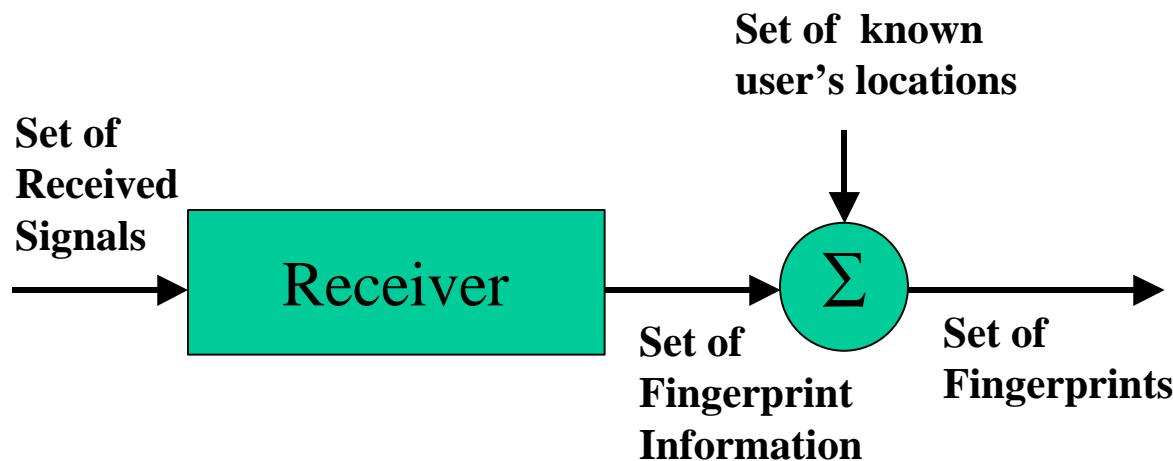


RadioCamera (US Wireless Corporation)

- RF based system for locating and tracking outdoor users
- Network based outdoor Geolocation
- Operation with Cellular technology
- Fingerprint Information based on Multipath Angular Power Profile at one Array Antenna per cell
- Off-Line phase gives a set of Fingerprints corresponding to Received Multipath Angular Power Profile $P_i(f)$ as a function of user's location (x_i, y_i) , $\{i = 1, 2, \dots, N\}$

Data Base (Set of Fingerprints)

Fingerprint Information	Known User's Location
$P_1(f)$	(x_1, y_1)
$P_2(f)$	(x_2, y_2)
$P_i(f)$	(x_i, y_i)
$P.(f)$	(x, y)
$P_N(f)$	(x_N, y_N)





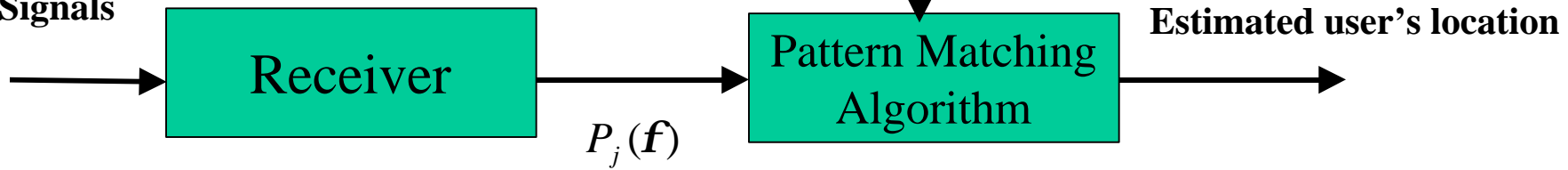
RadioCamera (US Wireless Corporation) (continued)

- For Real-Time phase, specific $P_j(f)$ is obtained from measured received signals and compared with recorded set of Fingerprints (database)
- A Pattern Matching Algorithm, using an Euclidean distance (in signal space), chooses location that minimizes distance between specific observed $P_j(f)$ and recorded set of Fingerprints, and therefore estimates user's location

Data Base (Set of Fingerprints)

Fingerprint Information	Known User's Location
$P_1(f)$	(x_1, y_1)
$P_j(f)$	(x, y)
$P_N(f)$	(x_N, y_N)

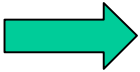

Received Signals





Proposed Indoor Geolocation System

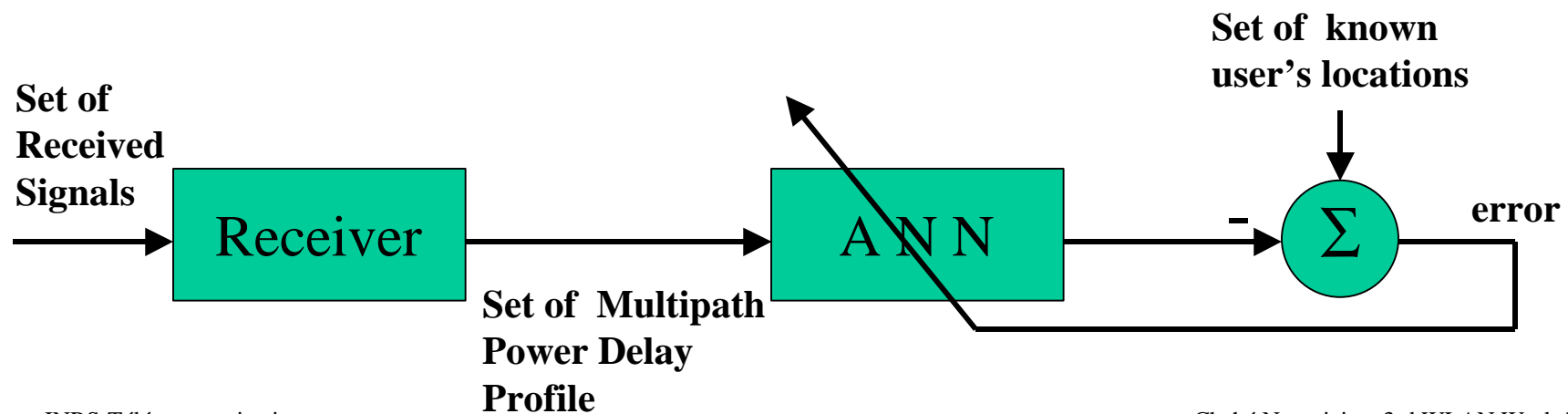
- **RF based system for locating and tracking users inside a mine**
- **Network based indoor Geolocation**
- **Operation with Cellular Radio, Impulse Radio and WLAN technologies**
- **Fingerprint Information based on Multipath Power Delay Profile $P_i(t)$ at one Fixed Station**

- **Artificial Neural Network (ANN) used to :**
 - **Learn Set of Fingerprints corresponding to Received Multipath Power Delay Profile $P_i(t)$ as a function of user's location (x_i, y_i) , $\{i = 1, 2, \dots, N\}$  **Training Phase****
 - **Obtain user's location from a specific received Multipath Power Delay Profile $P_j(t)$  **Recalling Phase****



Proposed Indoor Geolocation System (continued)

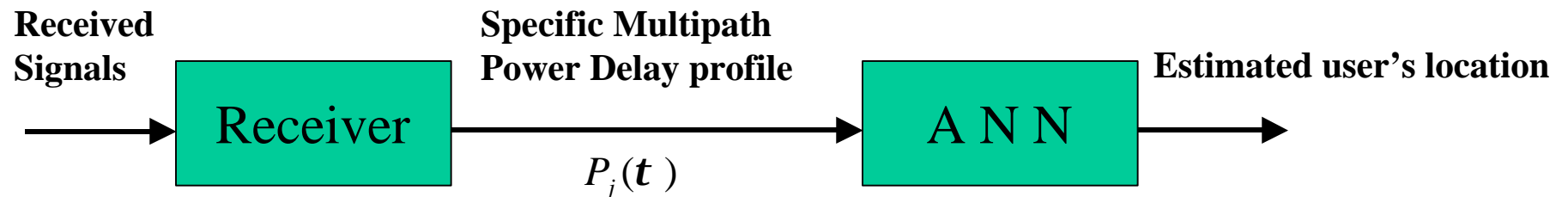
- **Back Propagation (BP) type ANN used as function approximator (Non Linear Regression)**
- **For Training Phase (Off-Line Learning Phase), each input of ANN corresponds to Multipath Power Delay Profile received by Fixed Station**
- **Training Phase of ANN corresponds to adjustment of its internal free parameters (weights and biases) by minimizing a performance function (mean square error)**
- **Training Phase is equivalent to recording the Set of Fingerprints**





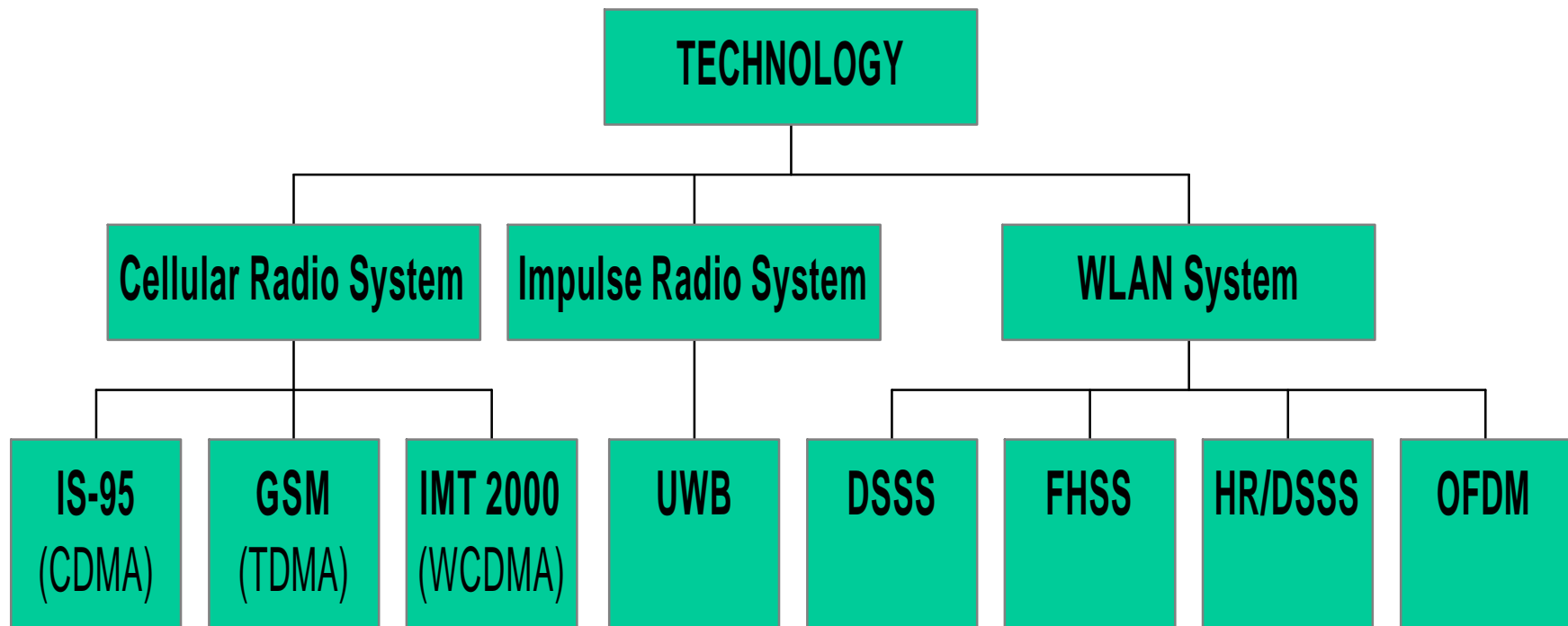
Proposed Indoor Geolocation System (continued)

- **Properly Trained ANN has a generalization property :**
 - **Robustness of ANN to input perturbations**
 - **Generalization rather than memorization of ANN (network gives right location for unseen and non trained input)**
- **For Recalling Phase (Real-Time Phase), Multipath Power Delay Profile of a specific Mobile Station is measured $P_j(t)$ and applied to the input of ANN (acting as Pattern Matching Algorithm)**
- **The output of ANN corresponds to the estimated value of user's location**





IMPLEMENTATION'S TECHNOLOGY





TECHNOLOGY versus TIME RESOLUTION

Cellular Radio	IS-95 (CDMA)	815 nanosecond
	GSM (TDMA)	3700 nanosecond
	IMT 2000 (WCDMA)	250 nanosecond
Impulse Radio	UWB	Few nanosecond
WLAN	DSSS	500 nanosecond
	FHSS	500 nanosecond
	HR/DSSS	90 nanosecond
	OFDM	20 nanosecond

Time resolution \cong Inverse of the Bandwidth



IMPORTANCE OF TIME RESOLUTION

- **In indoor environments :**
 - **The largest excess delay corresponding to the detectable Multipath component is approximately 500 nanosecond**
 - **The resolution of the Multipath Differential delays is in the nanosecond range**
- **To model Multipath Power Delay Profile (MPDP), the excess delay of all the Multipath components must be resolvable** ➡ *For the proposed system, a high time resolution is needed to obtain the MPDP*



IMPORTANCE OF TIME RESOLUTION

(continued)

- **Impulse Radio UWB and WLAN OFDM are good candidates for the proposed indoor Geolocation system**
- **Other Technologies can be used if some modifications are applied, such as :**
 - **Use of super-resolution methods**
 - **Use of over-sampling techniques**



CONCLUSION

- **Indoor Geolocation technique based on Multipath Power Delay Profile (MPDP) Fingerprint is a good choice in adverse environments (Multipath with NLOS)**
- **High Time Resolution is needed for MPDP measurements (the main challenge for the application of the proposed system)**
- **Use of Artificial Neural Network (ANN) as pattern matching algorithm has the following advantages :**
 - **Robustness of the system to input perturbations**
 - **Generalization rather than memorization of the network (network gives right location for unseen and non trained input)**
 - **Quick response during the recalling phase due to parallelism and off-line training**



CONCLUSION (continued)

- **Location accuracy depends on the size of the segmentation (square grid) of indoor environment layout used to define user's physical locations (information used in the training set of ANN)**
- **A new training phase is needed when indoor environment is modified**
- **Possibility to use redundancy of the system due to its simplicity (one fixed station with a trained ANN)**
- **Generalization of the user's location system from 2D to 3D is straight forward with ANN**



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